REVERSIBLE FLUID BALLOON ALTITUDE CONTROL CONCEPTS

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Abstract

A number of concepts for balloon altitude control have been developed such that temperature differentials in a planet's atmosphere can be used to provide the energy necessary to ascend and descend. In the most promising concepts, a fluid is evaporated in the lower, warmer atmosphere, thus filling a balloon and generating buoyancy for ascent. The fluid condenses in the upper, cooler atmosphere, thus decreasing buoyancy and allowing re-descent, Although the concept was originally developed to explore the atmosphere of Venus, the same principles are valid for almost all gaseous planets. A series of test flights has been successfully conducted on Earth in which a balloon system made multiple ascents and descents between a 5-km altitude and a 10-km altitude. Possible future Earth applications include weather forecasting and pollution studies.

I. Introduction

Research has recently been conducted at the NASA Jet Propulsion Laboratory (JPL), California Institute of Technology, to examine various means of raising and lowering balloon altitudes with no net cost of energy or mass to the balloon system itself. The initial application of this research has been for the exploration of the planet Venus, although it will bc shown that similar techniques can be used for most of the other gaseous atmosphere planets, including Earth.

The Venusian atmospheric environment is shown schematically in Fig. 1. The surface temperature is a scorching 460 ‘C and has a pressure of over ninety times Earth's surface pressures. The Venusian upper atmosphere between about 55 km to 60 km altitude, however, has temperatures and pressures quite close to those of Earth's lower atmosphere.

The original intent of this research was to find a means of having balloons descend to the Venusian surface for brief imaging and science investigations and then rise quickly to the cooler upper altitudes to allow instruments to cool and for data transmission to Earth.

The only Venusian atmospheric investigations to date have been two very short-lived Russian Venera landers in the 1970's and two Soviet–French–American balloons that hovered at a 54-km altitude for two days in 1985. Balloons capable of traversing across large altitude changes have the potential for amassing a much greater amount of planetary and atmospheric data, not only for Venus, but for all the gaseous atmosphere planets, including Earth.

Theory of Reversible Fluid Balloons

Phase Change Fluids

In the 1970's, the Russians did significant research into various types of controllable balloon systems for exploring the atmosphere of Venus. [1] One of the concepts they explored was to use an ammonia/water balloon system that would have both the ammonia and water evaporate at Venus' hot surface, thus filling a balloon. At higher altitudes, the water would preferably condense out, thus deflating the balloon and allowing re-descent to the surface. This effect can be seen in the Van't Hoff plot shown in Fig. 2. In this type of Log P vs. (l/T) plot, all fluid saturation lines form nearly a straight line. The intersection of the water properties curve and the Venusian atmospheric properties curve occurs at a 42-km altitude on Venus. Thus, a balloon filled with water at equilibrium would be 100% vapor below 42 km and 100% liquid above a 42-km altitude. In fact, since water is buoyant in the Venusian CO_2 atmosphere, the balloon would tend to stabilize at the 42-km altitude point.

Recent JPL studies[2] have shown that there are, in fact, many fluids that will have various stabilization altitudes in both the Venusian atmosphere and Earth's atmosphere (Fig. 2). Unfortunately, all of the fluids shown in Fig. 2 are heavier than their respective atmospheres, and thus it is necessary to also have a primary balloon filled with a light gas, such as helium or hydrogen. The double balloon system can then be sized such that when the phase change fluid is condensed, the double balloon system will have negative buoyancy, and when the phase change fluid is evaporated, the increase in total air displaced then results in positive buoyancy. The double balloon system thus allows for nearly constant altitude hovering for a whole series of altitudes.

In addition, if the phase change fluid is condensed and trapped in a pressure vessel, then the balloon system can descend well below its normal equilibrium level. In the scenario shown in Fig. 3, methylene chloride (CH_2Cl_2) is trapped in a vessel and descends to well below its equilibrium altitude of 58 km. A valve is then opened on the pressurized container, allowing the methylene chloride to evaporate, thus generating positive buoyancy and lifting the balloon higher.

It is in this manner that a planet's atmosphere can be used as a giant heat engine to permit ascent and descent of balloon systems. The lower, warmer atmosphere provides evaporation, thus causing ascent, while the upper, cooler atmosphere provides condensation, thus allowing re-descent.

Reversible Chemisorption

Phase change liquids are not the only reactions to form straight lines on Van't Hoff plots. Virtually all reversible gas/solid chemisorption reactions also form straight lines. For example, reversible ammoniated complexes and hydrides could also potentially be used to pinpoint various altitudes. The compound $CaCl_2(NH_3)_x$ releases ammonia vapor at Venus below 57 km and absorbs NH_3 vapor above 57 km. Similarly, the hydride compound $Fe_{0.8}Ni_{0.2}Ti(H)_x$ releases hydrogen below 50 km and absorbs hydrogen above 50 km.

These chemical reactions are, however, very susceptible to gaseous contamination that would ordinarily occur through slightly porous balloon membranes, whereas phase-change fluids are relatively forgiving in terms of contamination.

Fluid Mixtures

Another way to vary buoyancy and thus altitude is to use a single balloon filled with about 50% water (by volume) and with 50% of a more volatile fluid, such as ammonia or hydrogen. Ammonia could be stored as a pressurized liquid, and hydrogen could be stored in a hydride, such as $LiAlH_4$, which decomposes to release hydrogen at about 125 "C. Although a 100% water balloon would condense at about a 42-km altitude on Venus, a 50/50 mixture would begin condensation at about 49 km and would be 90'% condensed at 55 km. If the balloon were only 12% water, it would begin condensation at about 54 km, and would reach about 60 km when 90% of the water was condensed. Thus, one can pick the upper altitude simply by varying the percentage of water and non-condensable gas.

When the water is condensed, it can be collected in a lower, finned heat exchanger (Fig. 5), wherein the water will not appreciably evaporate/boil until descent is made to the water saturation altitude of 42 km. Thus, a single water/ammonia mixture balloon can be made that will automatically oscillate between altitudes of about 40 km and 60 km. At 40 km, imaging of the Venusian surface can occur well below the upper Venusian cloud levels, and at 60 km, the images can be sent to Earth while, simultaneously, the instruments can be cooled.

Applications to Other Planets

Fig. 5 contains Van't Hoff plots for various fluids as well as for the atmospheres of Jupiter, Saturn, Uranus, Neptune, and Titan, which is a satellite of Saturn and the only moon in our solar system with a gaseous atmosphere.

The most likely candidate for balloon phase change fluids for Jupiter and Saturn are ammonia, methane, or combinations thereof. Both planets have hydrogen contents of greater than 90%, and thus net changes in buoyancy can be effected to a maximum of only about 1 % of total system buoyancy.

There is a very good possibility, however, of using a phase change balloon of argon or possibly some mixtures for an altitude changing balloon on the Saturn moon, Titan, whose atmosphere is primarily nitrogen. Any number of fluids would work on Uranus and probably Neptune. Some of the more promising fluids are methane (maximum altitude is 3 bar at Uranus and 9 bar at Neptune), as well as nitrogen/hydrogen mixtures that could ascend to as high as 0.5 bar on either Uranus or Neptune. As with Venus and

Earth, the optimum phase change fluids tend to be heavier than the planetary atmospheres, and thus a primary light balloon, e.g., hydrogen, is necessary to maintain primary buoyancy.

It should be noted that phase change balloons do not appear suitable for the planet Mars, due to nearly isothermal characteristics of the very thin Martian atmosphere above about a 2 km altitude.

Earth Applications

A series of phase change balloon experiments has, in fact, been conducted in the Earth's atmosphere over the past two years. The results of this very successful series 01 ALtItude Control Experiments (ALICE) are being presented in another paper in this same conference series. [3] In the fourth ALICE flight on July 24, 1993, a double balloon system (helium, freon 114) was launched at JPL and tracked northeasterly across the California/Nevada deserts for 14 hours. During this time, the balloon performed 5 ascents and 5 descents between about a 5 km altitude and a 10 km altitude. This pure] y passive system did not trap the freon, but instead allowed the freon to evaporate in a special ribbed heat exchanger port ion of the lower freon balloon.

Future planned tests include trapping the freon in a pressure vessel to allow periodic landing of the balloon system. A lower, dangling rope, or "snake, " would be used to partially unload the balloon system and allow ground contact without balloon damage.

Potential future Earth applications of this technology include Earth weather forecasting and environmental studies, as well as surveillance and intelligence gathering. It may also be possible to use phase change fluid balloons to explore the nature of aviation-hazardous dust plumes from active volcanoes.

Conclusions

The development of phase change fluid balloon concepts is opening up a new phase in planetary exploration. lust as planetary orbiting satellites increased our knowledge over single flyby missions, so too will phase change fluid balloons surpass missions by single atmospheric probes.

Compact, yet powerful exploration systems will be able to carry out comprehensive imaging and science explorations on Venus, Titan, and the giant gas planets of Jupiter, Saturn, Uranus, and Neptune.

There are also a number of potential future missions of these types of missions on planet Earth. In particular, a single balloon aerobot can now potentially be used to make multiple tropospheric traverses to study weather or pollution patterns or to provide imaging data of selected sites with recovery (soft landing) of all hardware.

Future areas of study to be addressed include challenges in navigation and autonomous control, as well as balloon envelope materials for both cold and hot atmospheres.

References

1. Moskalanko, G. M., "Mekhanika Poleta v Atmosfere Venery," Mashinosteroenie Publishers, Moscow, 1978.

2. Jones, J. A., "Balloon Altitude and Temperature Control," JPL Notice of New Technology, NPO #19223, Jet Propulsion Laboratory, Pasadena, California, May 13, 1993.

3. Neck, K. et al., "Altitude Control Experiment Results," AIAA 32nd Space Congress, Clearwater, Florida, May 1995.

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Figure Captions

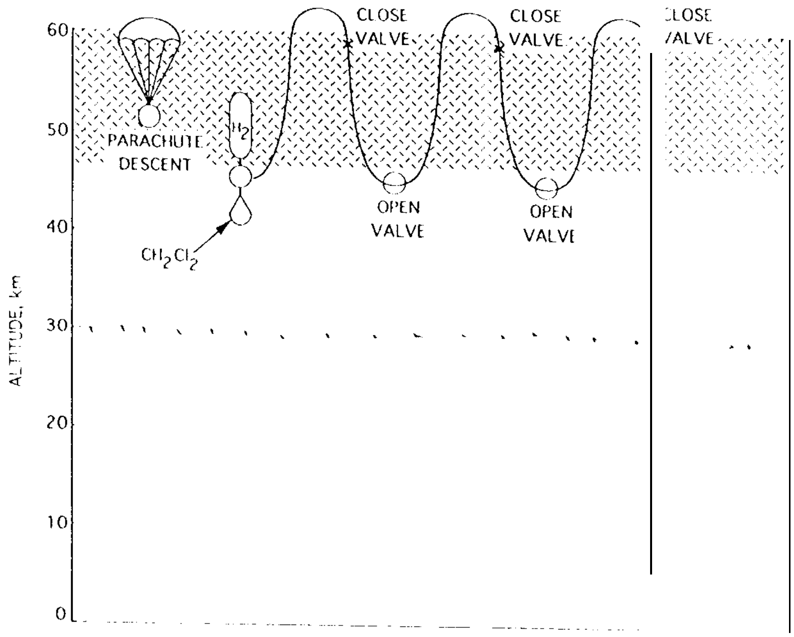
Fig. 1. Venus Environment.

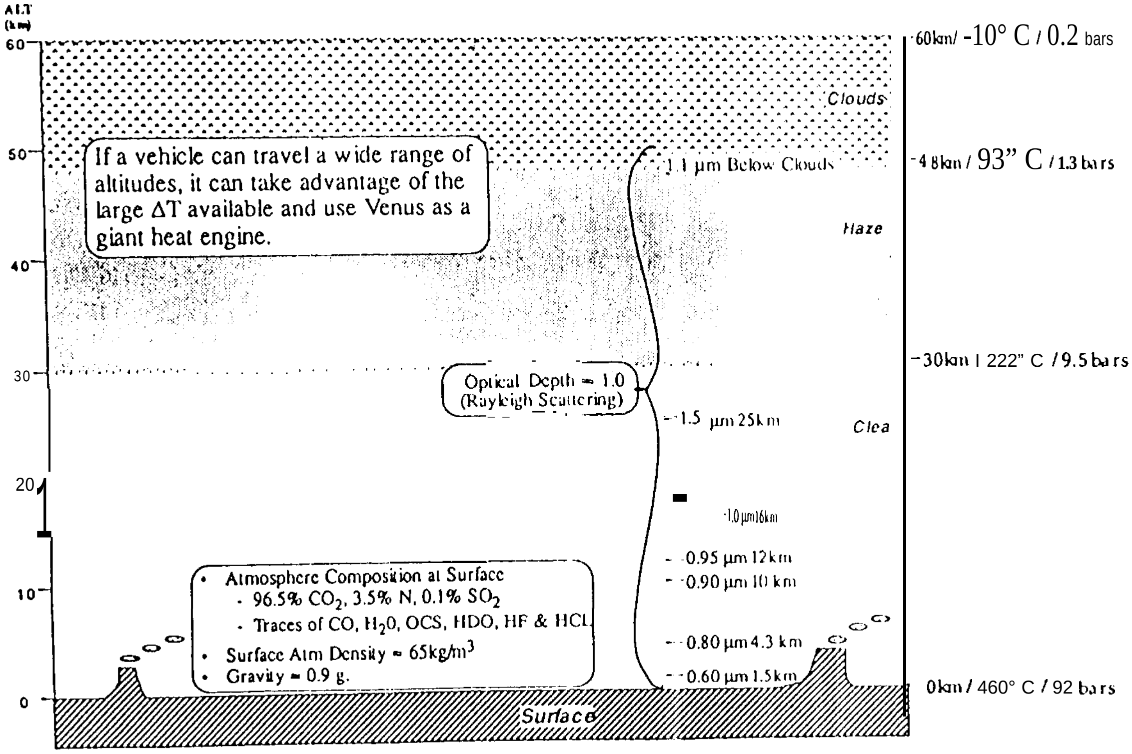
Fig. 2. Van’t Hoff Plot of Water and Venus Atmosphere.

Fig. 3. Venus Cloud Bobber Mission Profile.

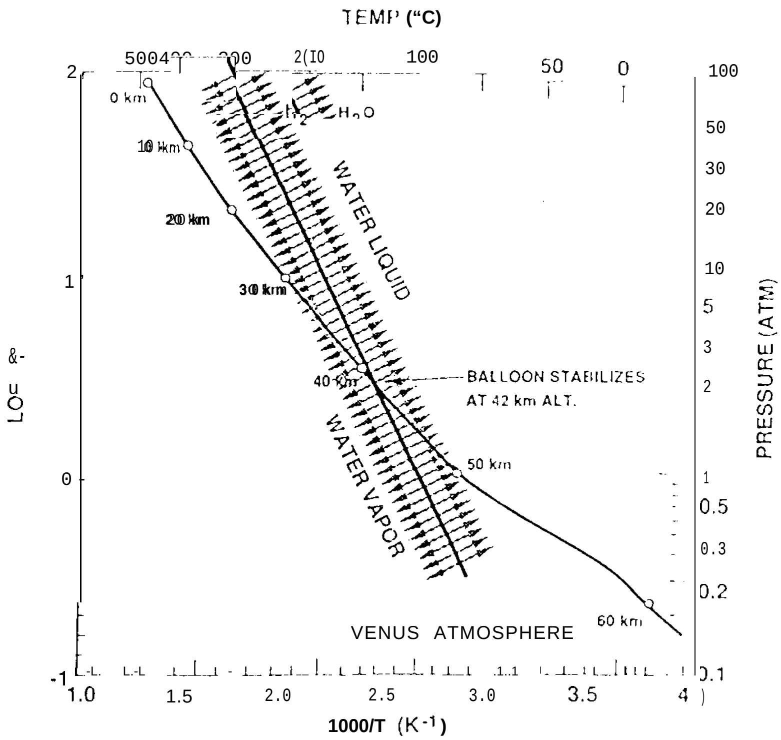
Fig. 4. Water Ammonia Mixture Balloon for Venus.

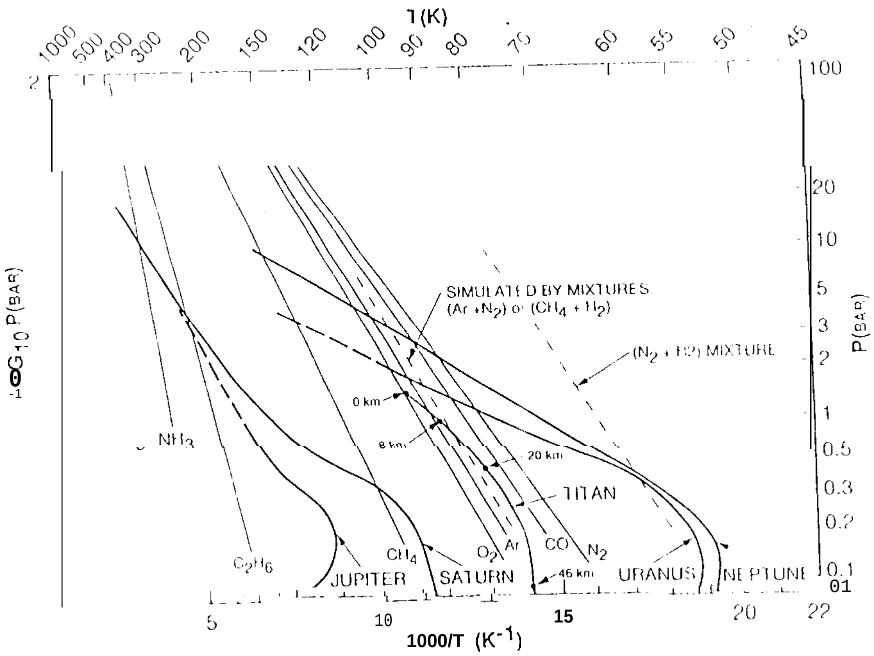
Fig. 5. Van’t Hoff Plots for Outer Solar System.

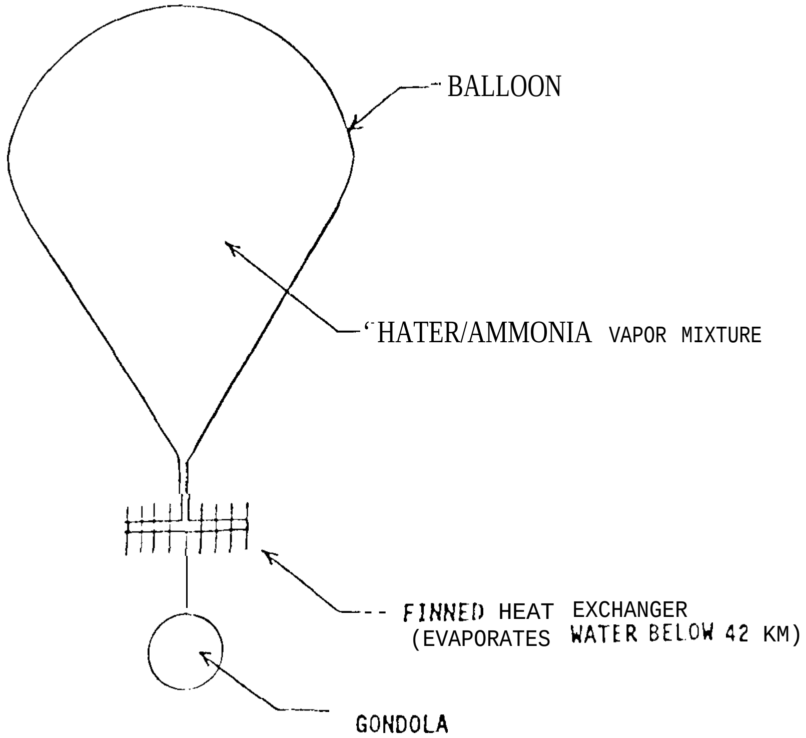

60
50
40
30
20
10
0
ALTITUDE, km
PARACHUTE DESCENT
H_2
CH_2Cl_2
CLOSE VALVE
OPEN VALVE
CLOSE VALVE
OPEN VALVE



ALT (km)
60
50
40
30
20
10
0
60km/ -10° C / 0.2 bars
Clouds
48km / 93" C / 1.3 bars
If a vehicle can travel a wide range of altitudes, it can take advantage of the large ΔT available and use Venus as a giant heat engine.
1.1 µm Below Clouds
Haze
30km I 222" C / 9.5 bars
Optical Depth ≈ 1.0 (Rayleigh Scattering)
1.5 µm 25km
Clea
1.0µm16km
0.95 µm 12km
0.90 µm 10 km
Atmosphere Composition at Surface
96.5% CO2, 3.5% N, 0.1% SO2
Traces of CO, H20, OCS, HDO, HF & HCL
Surface Atm Density ≈ 65kg/m3
Gravity ≈ 0.9 g.
0.80 µm 4.3 km
0.60 µm 1.5km
0km / 460° C / 92 bars
Surface


TEMP ("C)
100
50
0
0 km
10 km
20 km
30 km
40 km
50 km
60 km
WATER LIQUID
WATER VAPOR
BALLOON STABILIZES
AT 42 km ALT.
VENUS ATMOSPHERE
PRESSURE (ATM)
1000/T (K-1)


T(K)
1000
500
400
300
200
150
120
100
90
80
70
60
55
50
45
100
20
10
5
3
2
1
0.5
0.3
0.2
0.1
P(BAR)
LOG$_{10}$ P(BAR)
SIMULATED BY MIXTURES
(Ar+N$_2$) or (CH$_4$+H$_2$)
(N$_2$+H$_2$) MIXTURE
0 km
8 km
20 km
46 km
TITAN
NH$_3$
C$_2$H$_6$
CH$_4$
O$_2$
Ar
CO
N$_2$
JUPITER
SATURN
URANUS
NEPTUNE
5
10
15
20
22
1000/T (K^{-1})


BALLOON
HATER/AMMONIA VAPOR MIXTURE
FINNED HEAT EXCHANGER
(EVAPORATES WATER BELOW 42 KM)
GONDOLA